Informational Leaflet 152

ABUNDANCE AND COMPOSITION OF KING CRABS IN THE ALITAK AND KAGUYAK BAY AREAS DURING APRIL AND JUNE, 1970

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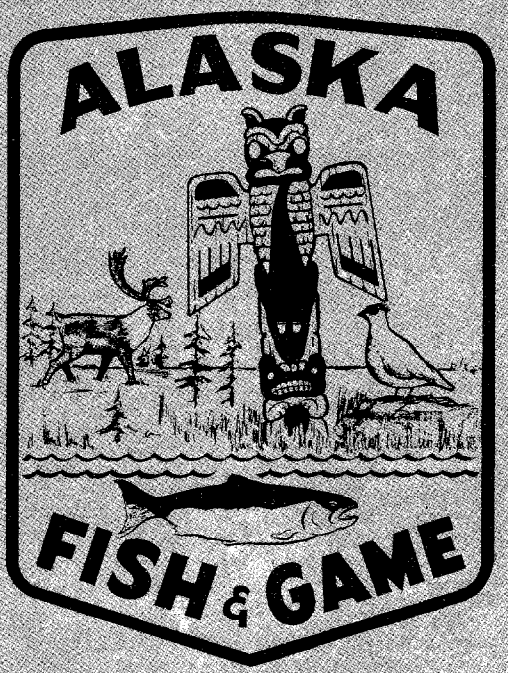

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ERRATA SHEET FOR INFORMATIONAL LEAFLET NO. 152

The section on abundance estimates on pages 7, 8 and 9 of the report included several notational errors. A complete and corrected version is as follows:

H : Total number of strata.

h : Subscript denoting the hth stratum, $h = 1 \ldots H$.

N_h : Total number of blocks sampled from the hth stratum, $h = 1 \ldots H$.

n_h : Number of blocks sampled from the hth stratum, $h = 1 \ldots H$.

i : Subscript denoting the ith block in the hth stratum, $i = 1 \ldots n_h$.

M_h : Total number of population tows per block in the hth stratum, $h = 1 \ldots H$.

m_h : Number of tows per block sampled in the hth stratum, $h = 1 \ldots H$.

j : Subscript denoting the jth tow in the ith block of the hth stratum, $j = 1 \ldots m_h$.

y_{hij} : Number of crabs captured from the ith tow in the jth block of the hth stratum.

$\bar{y}_{hi} = \frac{1}{m_h} \sum_{j=1}^{m_h} y_{hij}$: Sample mean per tow in the ith block of the hth stratum.

$\bar{\bar{y}}_h = \frac{1}{n_h} \sum_{j=1}^{m_h} \bar{y}_{hi}$: Overall sample mean per tow for the hth stratum.

$\bar{\bar{\bar{y}}}$: Sample mean per tow averaged over all strata.

The variance of the overal mean per tow within the hth stratum is estimated by:

$$\widehat{\text{Var}}\ (\bar{\bar{y}}_h) = \frac{(1 - f_{h1}) S_{h1}^2}{n_h} + \frac{f_{h1}\ (1 - f_{h2})\ S_{h2}^2}{m_h\ n_h} \qquad (1.1)$$

Where $f_{h1} = \frac{n_h}{N_h}$, $f_{h2} = \frac{m_h}{M_h}$

And $S_{h1}^2 = \sum_{i=1}^{n^h} (\bar{y}i - \bar{\bar{\bar{y}}})^2 / (n_h - 1)$,

$$S^2_{h2} = \sum_{i=1}^{n_h} \sum_{j=1}^{m_h} (y_{hij} - \bar{y}_{hi})^2 / n_h (m_h - 1)$$

The aggregate for the hth stratum is an estimate of the total number of crabs in that stratum and is obtained by

$$Agg_h = N_h \; M_h \; \bar{\bar{y}}_h \tag{1.2}$$

with variance estimated by

$$\widehat{Var\ (Agg_h)} = N_h^2 \; M_h^2 \; \widehat{Var\ (\bar{\bar{y}}_h)} \tag{1.3}$$

M_h is determined by the formula

$$M_h = \left[\frac{\text{Avg. sq. mi. per block for the hth stratum}}{\text{No. of sq. mi. per tow}} \right] \# \tag{1.4}$$

where # denotes the greatest integer value. Thus the total number of population tows for the hth stratum is $N_h \; M_h$.

Means and variances of the strata are combined by weighting according to the number of population tows in each stratum. I.e., the mean strata is computed by:

$$\bar{\bar{y}} = \sum_{h=1}^{H} W_h \; \bar{\bar{y}}_h \tag{1.5}$$

and the variance by

$$\widehat{Var\ (\bar{\bar{y}})} = \sum_{h=1}^{H} W_h^2 \; \widehat{Var\ (\bar{\bar{y}}_h)}, \tag{1.6}$$

where $W_h = \dfrac{N_h M_h}{\sum_{h=1}^{H} N_h M_h}$,

The overall aggregate estimates the total number of crabs in the Alitak area (or that portion sampled) and is given by

$$Agg = \left(\sum_{h=1}^{H} N_h M_h \right) \bar{\bar{y}}_h \; . \tag{1.7}$$

with the variance estimated by

$$Var\ (Agg) = \left(\sum_{h=1}^{H} N_h M_h \right)^2 \; Var\ (\bar{\bar{y}}) \, . \tag{1.8}$$

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ABUNDANCE AND COMPOSITION OF KING CRABS IN THE ALITAK AND KAGUYAK BAY AREAS DURING APRIL AND JUNE, 1970

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INTRODUCTION

A study of king crab brood stocks and age class abundance was initiated in July 1969 with three long-term goals[1/]: 1) to determine if selective fishing for male king crabs has resulted in unbalanced sex ratios; 2) to determine how age-class abundance of king crabs is related to brood stock condition; and 3) to determine if desired levels of harvest can be established based upon knowledge of the biology and abundance of king crabs. Success in achieving these goals is dependent upon development of valid sampling techniques and the repeated application of these techniques over a period of several years.

Sampling of king crab populations for this study was begun in April 1970. Included herein are the results and analysis of the first year's research.

1/ This investigation was partially financed by the Commercial Fisheries Research and Development Act (P.L. 88-309 as amended) under sub-project 5-22-R, Contract Number 14-17-0005-270.

METHODS

Study areas

Two specific areas were selected for study during 1970, one in the vicinity of Alitak Bay and another in the vicinity of Twoheaded Island, Kaguyak Bay and Geese Channel (Figure 1). Throughout this report the two areas will be referred to as the Alitak study area and the Kaguyak study area respectively.

These areas were chosen on the basis of their past history as king crab mating grounds and as probable areas of abundance of sub-legal male king crabs. Boundaries were chosen to exclude shallow, rocky, non-trawlable waters. Priority was given to thorough sampling of the Alitak study area and the remainder of this report will largely concern that area. The Alitak area included approximately 130 square miles[2/] of ocean floor ranging from 5 to 57 fathoms in depth. The Kaguyak study area included approximately 55 square miles of ocean floor from 10 to 47 fathoms in depth.

Sampling design

The two study areas were stratified on the basis of depth. Strata were then divided into blocks of approximately equal size using a polar planimeter to measure area (Appendix Table 1). The Alitak area contained 82 blocks (Figure 2) and the Kaguyak area contained 41 (Figure 3).

Sampling effort, i.e. the number of sampled blocks per stratum, was distributed in proportion to the relative size of the strata. One or more trawl hauls were made within each block selected. Sampled blocks were selected randomly and the starting points of the tows within a block were assumed to be randomly chosen at the time of actual sampling. Thus, within each stratum, the two-stage sampling structure discussed by Cochran (1963) was employed, with blocks as first stage units and tows as second stage units.

Sampling periods

Field activity was divided into two periods: April 25-30, 1970 and June 1-26, 1970. In April, sampling was limited to strata 1, 2 and 3 (5-29 fathoms) in the Alitak study area. During June all strata of both study areas were sampled. Sampling blocks were randomly chosen for each of the two periods.

2/ Throughout this report, the term "mile" will refer to nautical mile (6,076 feet).

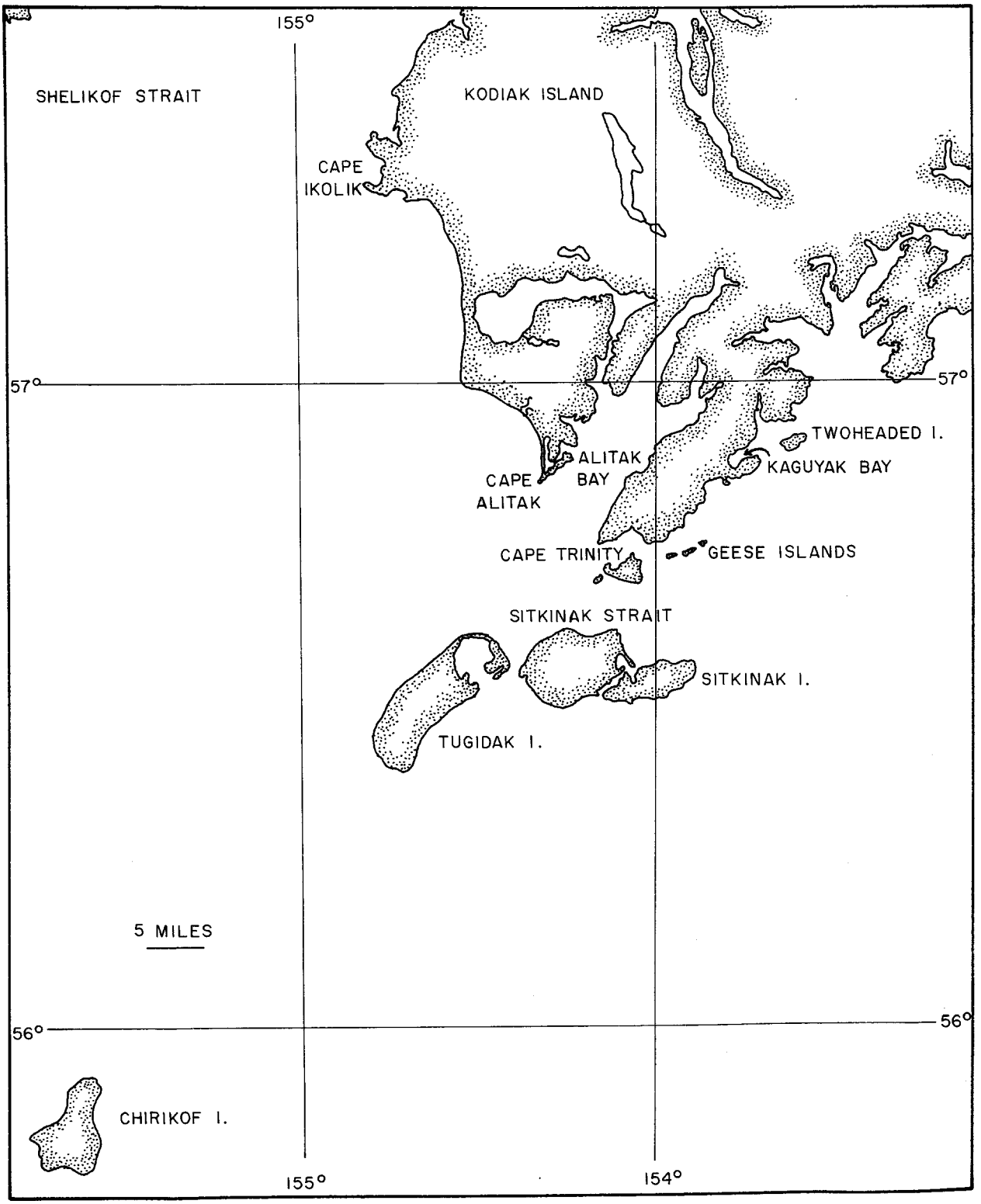

Figure 1. South end of Kodiak Island showing Alitak Bay and Kaguyak Bay where study areas were located.

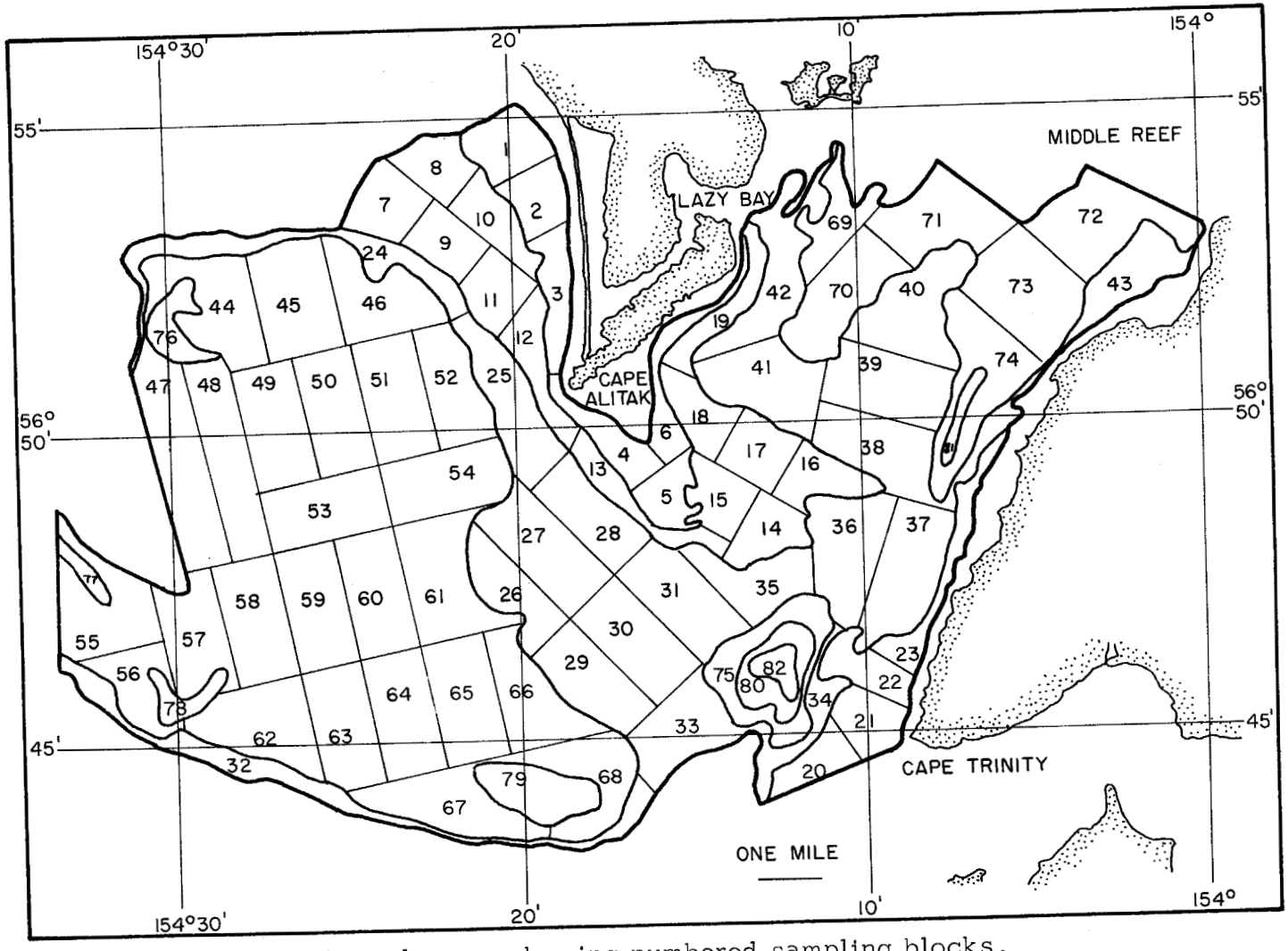

Figure 2. Alitak study area showing numbered sampling blocks.

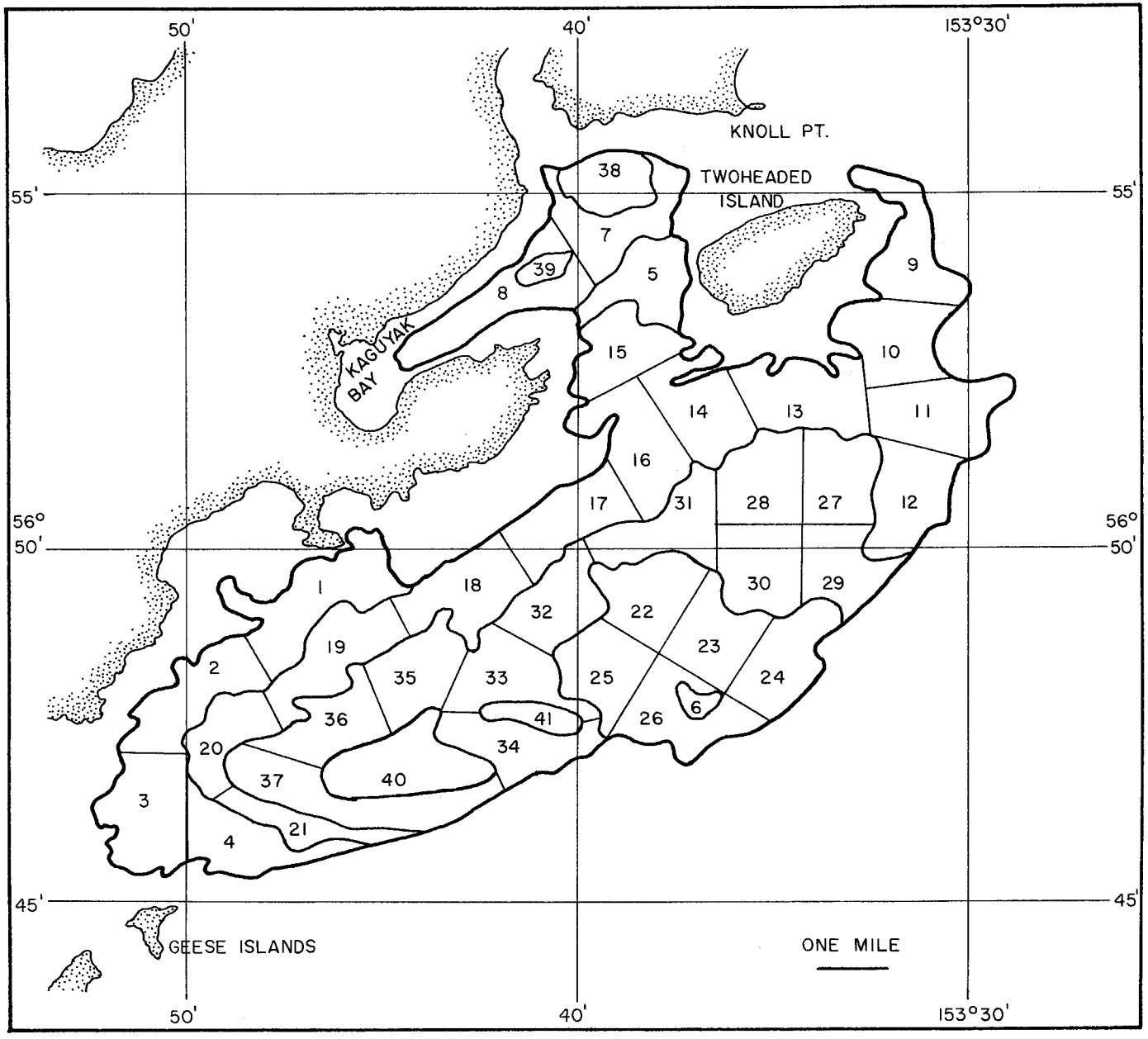

Figure 3. Kaguyak study area showing numbered sampling blocks.

Sampling gear

A beam trawl was used as the primary sampling gear. This trawl has a span of 18 feet between the shoes and is webbed with 1-1/2 inch stretched mesh nylon throughout. The trawl was towed at a speed of approximately 2 knots using a warp-depth ratio of about 3:1. Most tows were 1 mile in length. King crab pots were used to capture crabs for tagging and to provide additional crab samples for examination and measurement.

Initial processing of samples

All king crabs in each trawl sample were examined and nearly all were measured. A small percentage of crabs could not be measured due to carapace damage. Carapace length, sex and shell age were recorded. Female crabs were also examined macroscopically for egg clutch size, which was classified as full, partial or absent (non-ovigerous). Egg samples were collected from some of the new-shell female king crabs in both study areas in order to determine the frequency of unfertilized external eggs. A small portion of the egg mass, including eggs, egg cases, pleopodal hairs and associated animals was removed with a forceps from the outermost surface of the egg clutch of the female, and was preserved in Bouin's fixative.

A size criterion of sexual maturity, based on earlier studies of maturity in the king crab which are summarized in Powell and Nickerson (1965), was used in this study. King crabs of both sexes were considered to be mature at 100 mm carapace length and all crabs smaller than 100 mm were considered immature. Our observations of the size at maturity of female king crabs are discussed briefly later in the report.

Uninjured king crabs from both pot and trawl catches (primarily the former) were isthmus-tagged (Gray, 1965) with numbered orange spaghetti tags and released in the Alitak study area to determine the extent of dispersion.

Microscopic examination of eggs

Egg samples from new-shell female crabs were examined in the laboratory using a binocular dissecting microscope (10-30X). Eggs not showing cleavage or embryonic development were assumed to be unfertilized. If no unfertilized eggs were observed during careful microscopic examination, the entire clutch was considered to be 100 percent fertilized. A similar procedure was followed when all eggs were unfertilized. However, if the sample contained both fertilized and unfertilized eggs, two sub-samples of approximately 100 eggs each were

removed and the numbers of fertilized and unfertilized eggs counted. The percent of fertilized eggs in a sample was calculated as the average of the two sub-samples.

Abundance estimates

The trawl sampling design was planned to enable the estimation of the numbers of king crabs present within the study areas. The following notation system has been used in the formulae for the computation of the means, aggregates and variances:

H : Total number of strata.

h : Subscript denoting the hth stratum, $h = 1 \ldots H$.

N_h : Total number of blocks in the hth stratum, $h = 1 \ldots H$.

n_h : Number of blocks sampled from the hth stratum, $h = 1 \ldots H$.

i : Subscript denoting the ith block in the hth stratum, $i = 1 \ldots n_h$.

M_h : Total number of population tows per block in the hth stratum, $h = 1 \ldots H$.

m_h : Number of tows per block sampled in the hth stratum, $h = 1 \ldots H$.

j : Subscript denoting the jth tow in the ith block of the hth stratum, $j = 1 \ldots m_h$.

Y_{hij} : Number of crabs captured from the ith tow in the jth block of the hth stratum.

$\bar{Y}_{hi} = \frac{1}{m_h} \sum_{j=1}^{m_h} Y_{hij}$: Sample mean per tow in the ith block of the hth stratum.

$\bar{\bar{Y}}_h = \frac{1}{n_h} \sum_{j=1}^{m_h} \bar{Y}_i$: Overall sample mean per tow for the hth stratum.

$\bar{\bar{Y}}$: Sample mean per tow averaged over all strata.

The variance of the overall mean per tow within the hth stratum is estimated by:

$$\widehat{\text{Var}}\ (\bar{\bar{Y}}_h) = \frac{(1 - f_{h1}) S^2_{h1}}{n_h} + \frac{f_{h1}\ (1 - f_{h2})\ S^2_{h2}}{m_h\ n_h} \qquad (1.1)$$

Where $f_{h1} = \frac{n_h}{N_h}$, $f_{h2} = \frac{m_h}{M_h}$

And $S^2_{h1} = \sum_{i=1}^{n_h} (\bar{y}i - \bar{\bar{y}})^2 / (n_h - 1)$,

$$S^2_{h2} = \sum_{i=1}^{n_h} \sum_{j=1}^{m_h} (Y_{hij} - \bar{y}_{hi})^2 / n_h (m_h - 1)$$

The aggregate for the hth stratum is an estimate of the total number of crabs in that stratum and is obtained by

$$\text{Agg}_h = N_h\ M_h\ \bar{\bar{Y}}_h \qquad (1.2)$$

with variance estimated by

$$\widehat{\text{Var}\ (\text{Agg}_h)} = N^2_h\ M^2_h\ \widehat{\text{Var}\ (\bar{\bar{Y}}_h)} \qquad (1.3)$$

M_h is determined by the formula

$$M_h = \left[\frac{\text{Avg. sq. mi. per block for the hth stratum}}{\text{No. of sq. mi. per tow}}\right] \# \qquad (1.4)$$

where # denotes the greatest integer value. Thus the total number of population tows for the hth stratum is $N_h\ M_h$.

Means and variances of the strata are combined by weighting according to the number of population tows in each stratum. I.e., the mean overall strata is computed by:

$$\bar{\bar{y}} = \sum_{h=1}^{H} W_h\ \bar{\bar{y}}_h \qquad (1.5)$$

and the variance by

$$\widehat{\text{Var}\ (\bar{\bar{Y}})} = \sum_{h=1}^{H} W^2_h\ \widehat{\text{Var}\ (\bar{\bar{y}}_h)}, \qquad (1.6)$$

where $W_h = \frac{N_H\ M_h}{\sum_{h=1}^{H} N_h\ M_h}$,

The overall aggregate estimates the total number of crabs in the Alitak area (or that portion sampled) and is given by

$$Agg = \left(\sum_{h=1}^{H} N_h M_h \right) \bar{\bar{Y}} . \qquad (1.7)$$

with the variance estimated by

$$Var\ (Agg) = \left(\sum_{h=1}^{H} N_h M_h \right)^2 \quad Var\ (\bar{\bar{Y}}) . \qquad (1.8)$$

Computer programs were written to tabulate the data and obtain the estimates enumerated above plus estimates of sex ratios and the proportion of non-ovigerous females for tows, blocks and strata. Programs were also written to transfer the data from cards to tape for permanent storage.

Distribution of sampling effort

Sampling effort was primarily distributed within each study area on the basis of cost, since previous estimates of sampling variability were not available. The initial plan for April called for a sample of 15 blocks with three tows per block. However, after the field season commenced it became evident that such a program was unreasonable because of time restrictions, and the number of tows per block was reduced to two. This plan still permitted the estimation of within-block variance. A maximum number of tows per block was desired in order to obtain a representative sample and to reduce the within-block variability as much as possible. Ideally, five or six tows should have been made in each block selected, but this was impossible due to the restriction of funds for the project.

Sample size for the June period was determined partially on the basis of estimates of within- and between-block variability obtained from the April survey. Since sampling in April was confined to strata 1, 2 and 3, variability estimates were obtainable for those strata only.

The computation of the optimum number of tows (m_h opt) based on estimates of variability from a pilot study is discussed by Cochran (1963). Denoting C, as the total cost of the survey and c_1, c_2 as the costs of sampling first and second stage units respectively, and assuming the cost function $C = c_1 n + c_2 n m$, the estimate of m_h opt is

$$m_h \text{ opt} = \frac{s_2}{\sqrt{s_1^2 - (s_2^2 / m'_h)}} \sqrt{c_1 / c_2} \qquad (1.9)$$

where m'_h denotes the value of m_h in the pilot survey and s_1^2, s_2^2 are defined in the previous section. The values of c_1 and c_2 were obtained from time estimates for the April survey and found to be approximately equal. Thus equation (1.9) reduces to

$$m_h \text{opt} = \frac{s_2}{\sqrt{s_1^2 - s_2^2 / m_h'}} \quad . \tag{1.10}$$

$m_h$opt were computed for males and females in strata 1, 2 and 3 (Table 1).

Table 1. Comparison of number of tows and estimates of m_{opt} .

Stratum	m_{opt} Males	m_{opt} Females	Actual m
1	2	M_h	5
2	1	5	2
3	1	1	2

The differences between m_{opt} and actual m may be explained as follows:

For stratum 1 $s_2^2 / m_h' < s_1^2$ indicates m_h should be taken equal to M_h; i.e., one stage sampling should be employed. Since one stage sampling (sampling entire blocks) would have been impossible in this survey, the number of tows completed per block was as high as possible with respect to the time available for sampling.

In stratum 2 the initial plan called for five tows per block. However, after sampling two blocks, 13 and 18, it became evident that the plan was too ambitious and very few crabs were captured. Sampling was subsequently reduced to two tows per block.

Strata 3-6 were sampled with $m_h = 2$ in order to obtain an estimate of within-block variability. Thus the final analysis for the June sampling was performed on six strata with five tows per block taken in the first stratum and two tows per block taken in the remaining five. Although the computed m_{opt} could not be followed exactly, the calculations did provide a guide for determining and distributing sampling effort.

RESULTS

Alitak study area

April sampling:

In April, 31 beam trawl tows were made in the Alitak study area. All 15 of the pre-selected blocks were sampled (Table 2). Two replicate tows were made in each of 14 blocks and three tows were made in the remaining one. All tows except one were 1 mile in length. A total of 1,998 king crabs, 481 males and 1,517 females, were captured in the trawl samples (Table 3). At least one male and one female crab were captured in each tow.

June sampling:

Seventy-nine tows were made in the Alitak area in June. Thirty-four blocks representing all depth strata were sampled (Table 4). Three of the pre-selected blocks were found to be too rocky for trawling (as indicated by the fathometer), necessitating the random selection of three replacement blocks. The number of tows per block varied from one to five as previously described. Most of the tows were 1 mile in length, however in several blocks, shorter tows were made due to block dimensions.

Trawl sampling in June produced a total of 1,336 king crabs, consisting of 557 males and 779 females (Table 5). Fifteen tows yielded no king crabs and over half of the tows yielded four crabs or less.

Abundance estimates:

The number and density (crabs per square mile) of king crabs in the Alitak area were estimated utilizing April and June trawl samples. Eight tows were omitted from the calculations in order to obtain an equal number of tows per block within each stratum. Catches in tows of non-standard length was adjusted proportionately before estimates were calculated. Those modifications of the raw data had little effect, since the tows involved captured very few crabs.

During the April sampling period, an estimated 1.4 million king crabs occupied the 61 square miles comprising strata 1-3 of the Alitak area (Table 6 and Appendix Table 2). Estimates for males and females were 0.33 million and 1.07 million respectively. Average density for the strata sampled was estimated to be 23,058 crabs per square mile. Although the area sampled in June was more than twice as large as that sampled in April, the estimated number of king crabs in June was only 0.93 million. Estimates for males and females were 0.39 million

Table 2. Strata and blocks sampled in the Alitak study area, April 1970[1/].

Stratum 1 (5-9 fms)		Stratum 2 (10-19 fms)		Stratum 3 (20-29 fms)	
Block no.	No. tows	Block no.	No. tows	Block no.	No. tows
4	2	14	2	26	2
5	2	17	2	28	2
		18	2	29	2
		19	3	30	2
				35	2
				37	2
				39	2
				40	2
				42	2

1/ Strata 4-6 were not sampled.

Table 3. Number of king crabs captured in trawl samples in the Alitak study area, April 1970.

Stratum	Number samples	Females			Males			Total crabs
		New-shell	Old-shell	Total	New-shell	Old-shell	Total	
1	4	11	11	22	28	3	31	53
2	9	278	67	345	69	19	88	433
3	18	602	548	1,150	314	48	362	1,512
Total	31	891	626	1,517	411	70	481	1,998

Table 4. Strata and blocks sampled and number of sample tows in the Alitak study area, June 1970.

Stratum 1 (5-9 fms)		Stratum 2 (10-19 fms)		Stratum 3 (20-29 fms)		Stratum 4 (30-39 fms)		Stratum 5 (40-49 fms)		Stratum 6 (50-59 fms)	
Block #	# tows	Block #	# tows	Block #	# tows	Block #	# tows	Block #	# tows	Block #	# tows
5	5	9	1	24	2	45	2	79	2	82	2
6	5	13	5	26	2	46	2	81	2		
		14	2	29	2	49	2				
		17	2	31	2	50	2				
		18	5	35	2	52	2				
				39	2	54	2				
				40	2	56	2				
				42	2	57	2				
				43	2	59	2				
						62	2				
						66	2				
						69	2				
						70	2				
						72	2				
						74	2				

Table 5. Number of king crabs captured in trawl samples in the Alitak study area, June 1970.

Stratum	Number samples	Females			Males			Total crabs
		New-shell	Old-shell	Total	New-shell	Old-shell	Total	
1	10	4	1	5	3	0	3	8
2	15	13	0	13	16	3	19	32
3	18	406	6	412	279	3	282	694
4	30	280	7	287	225	3	228	515
5	4	54	1	55	24	1	25	80
6	2	7	0	7	0	0	0	7
Total	79	764	15	779	547	10	557	1,336

Table 6. Estimates of numbers of king crabs in the Alitak study area, April and June 1970.

Sampling period	Population estimates	70% Confidence limits		90% Confidence limits		95% Confidence limits	
		Lower	Upper	Lower	Upper	Lower	Upper
April [1/]							
Males	0.33×10^6	0.23×10^6	0.43×10^6	0.17×10^6	0.49×10^6	0.13×10^6	0.53×10^6
Females	1.07×10^6	0.72×10^6	1.42×10^6	0.51×10^6	1.63×10^6	0.40×10^6	1.74×10^6
June							
Males	0.39×10^6	0.25×10^6	0.53×10^6	0.18×10^6	0.60×10^6	0.13×10^6	0.65×10^6
Females	0.54×10^6	0.38×10^6	0.70×10^6	0.29×10^6	0.79×10^6	0.24×10^6	0.84×10^6

1/ April estimates for strata 1-3 only.

and 0.54 million respectively. Average crab density for the entire Alitak study area in June was estimated to be 7,082 crabs per square mile, less than one-third of the estimated density in April.

Sample variance was found to be consistently high, resulting in wide confidence intervals (Table 6). A detailed analysis of variance is not available at this time, however one major factor in the high variance was the large between-block variation within strata. For example in April, stratum 3 included the two blocks of highest estimated crab density (blocks 28 and 30) as well as the block of lowest density (block 40) and blocks of intermediate density (Figure 4). Estimated density among the blocks within stratum 2 also varied considerably. Between-block variability was also apparent in strata 3 and 4 during June (Figure 5).

Size and shell age composition:

Male king crabs taken in the trawl samples ranged from 52 mm to 180 mm in carapace length and included exuviant (new-shell) and anexuviant (old-shell) crabs. Approximately 93 percent of the males captured were of sublegal size (Appendix Tables 3-5).

The size distribution of new-shell males caught in April was basically unimodal with over half of crabs between 115 mm and 134 mm in carapace length (Figure 6). A weak secondary mode was evident at approximately 87 mm. The distribution of June new-shell males was bimodal with the weaker of the two June modes occurring at approximately the same size as the single April mode. There was a more prominent mode at approximately 77 mm carapace width. Most of the small crabs represented by the latter mode were captured in stratum 4, which was not sampled during April. During both sampling periods, new-shell male crabs in the 95 mm to 104 mm length range were relatively scarce.

Old-shell male king crabs were scarce in the trawl samples compared to new-shell males, particularly during June. Of the 70 old-shell males captured in April, 27 crabs (38%) were of sublegal size (Figure 6). Only 10 old-shell males were captured in June.

Female king crabs ranged from 61 mm to 165 mm in carapace length (Appendix Tables 6-8). During the April sampling period the female molt was in progress. Most females less than 125 mm carapace length had already molted, while most of the larger females were in a pre-molt condition (Figure 7). The length distribution of new-shell females in the April samples exhibits a prominent mode at 112 mm and a weaker mode at 132 mm. The distribution of April old-shell females is clearly unimodal. All but 15 of the female king crabs taken in June had molted so the length distribution of June old-shell females

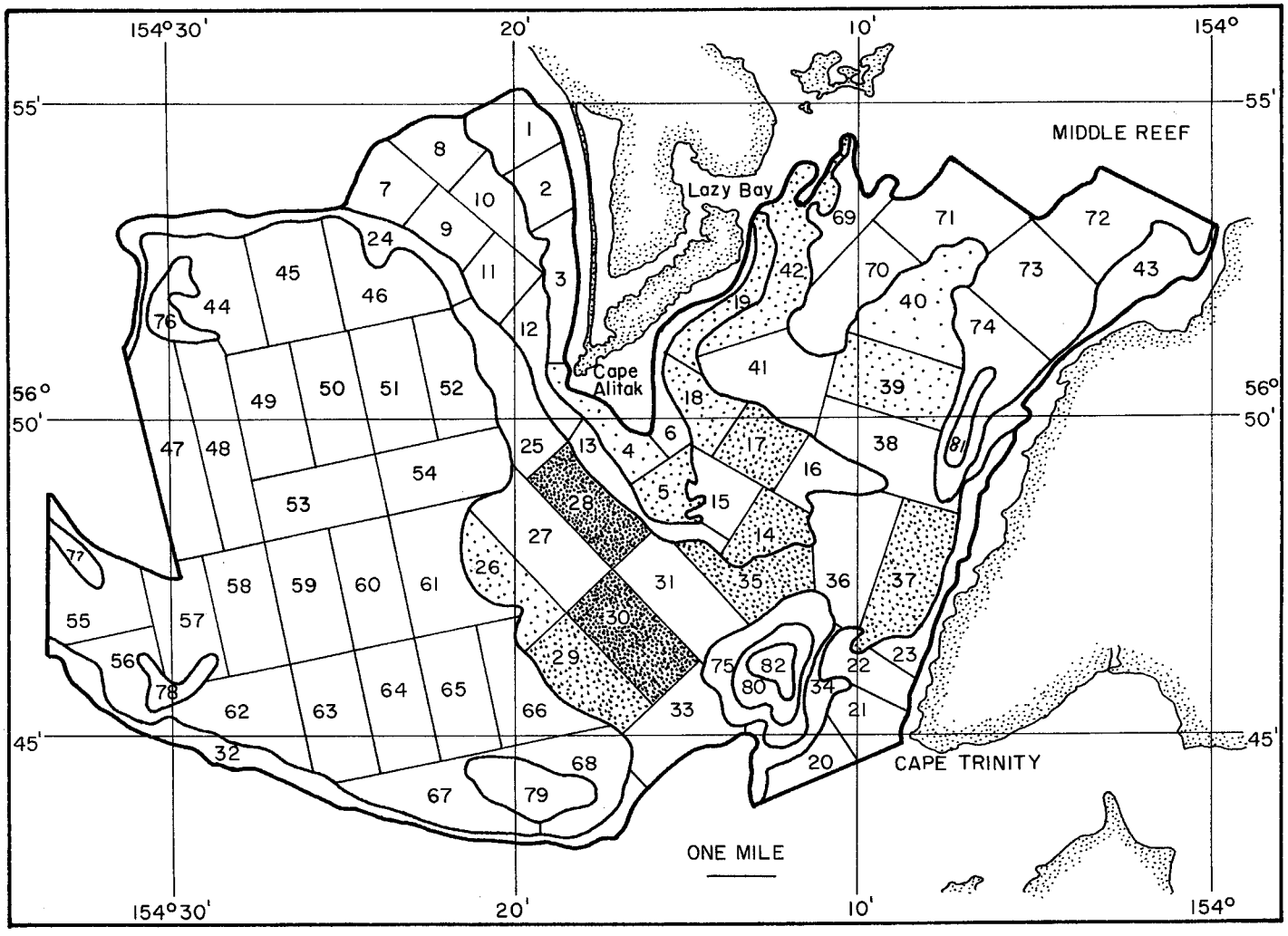

Figure 4. Estimated crab density within blocks sampled in April 1970 in the Alitak study area.

over 30,000 crabs/sq. mi.

15,000-30,000 crabs/sq. mi.

5,000-15,000 crabs/sq. mi.

less than 5,000 crabs/sq. mi.

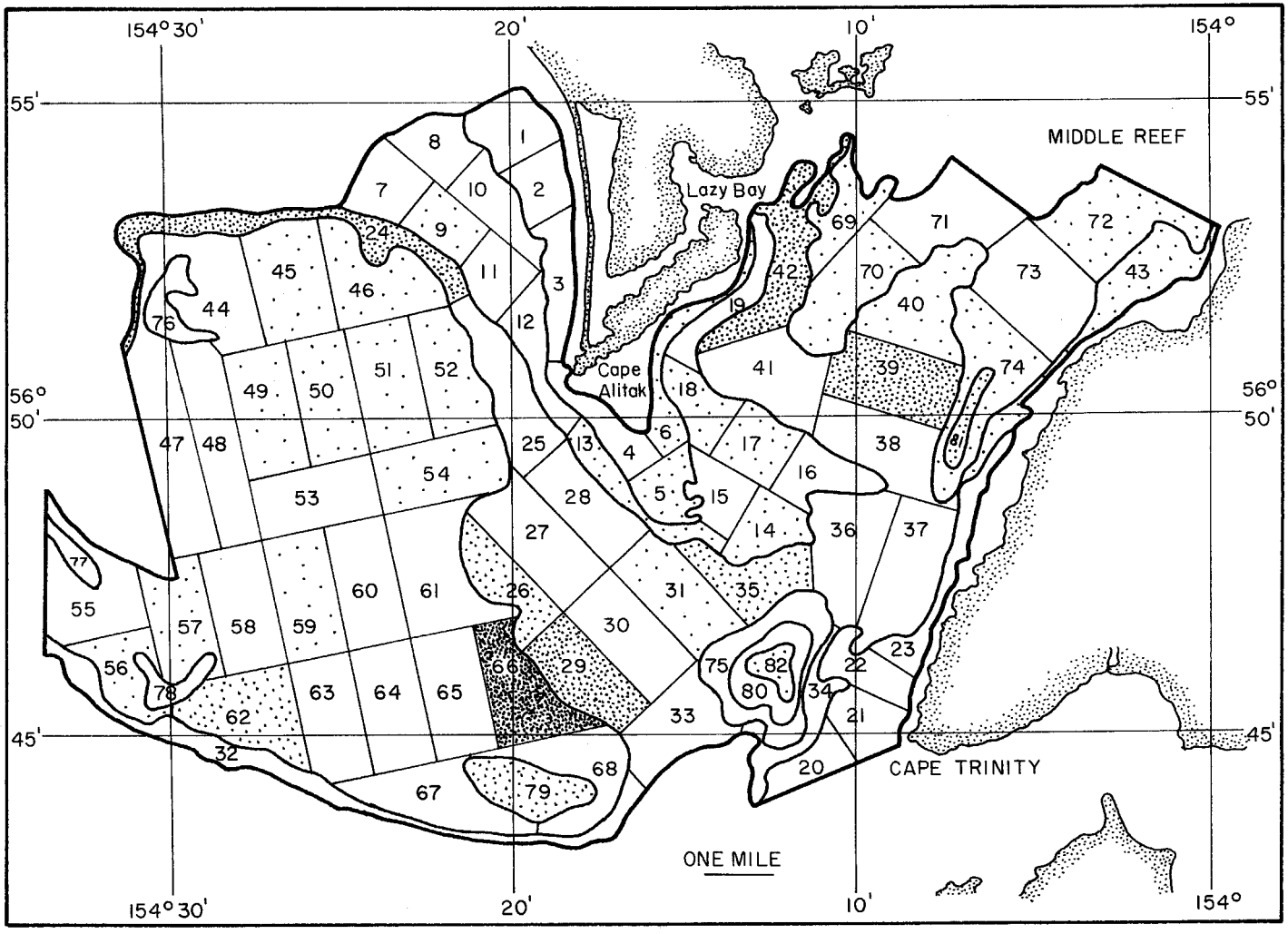

Figure 5. Estimated crab density within blocks sampled in June 1970 in the Alitak study area.

over 30,000 crabs/sq. mi.

15,000-30,000 crabs/sq. mi.

5,000-15,000 crabs/sq. mi.

less than 5,000 crabs/sq. mi.

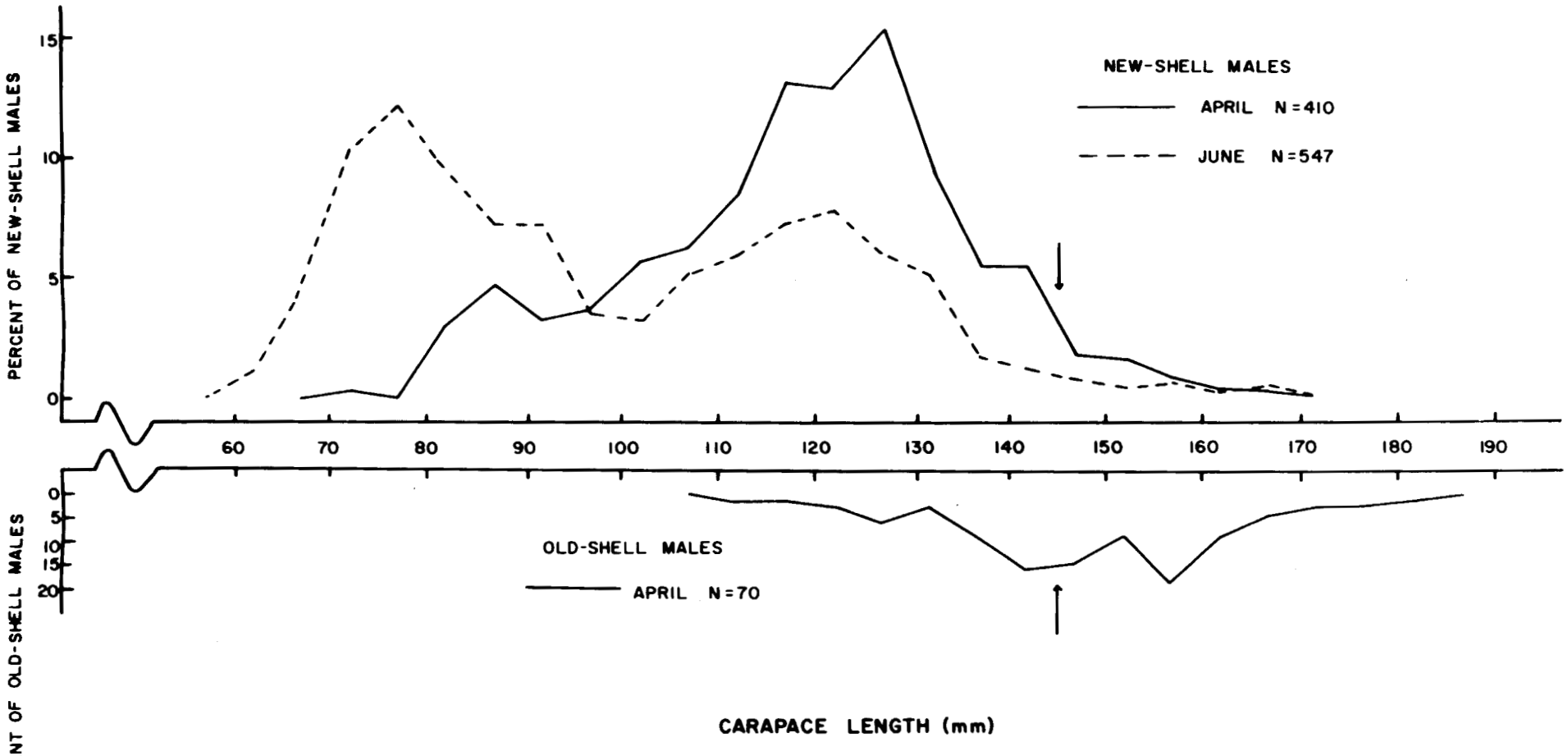

Figure 6. Carapace length distribution of male king crabs captured in the Alitak study area, April and June 1970. Arrows indicate approximate size at recruitment to the fishery (seven inches carapace width including spines).

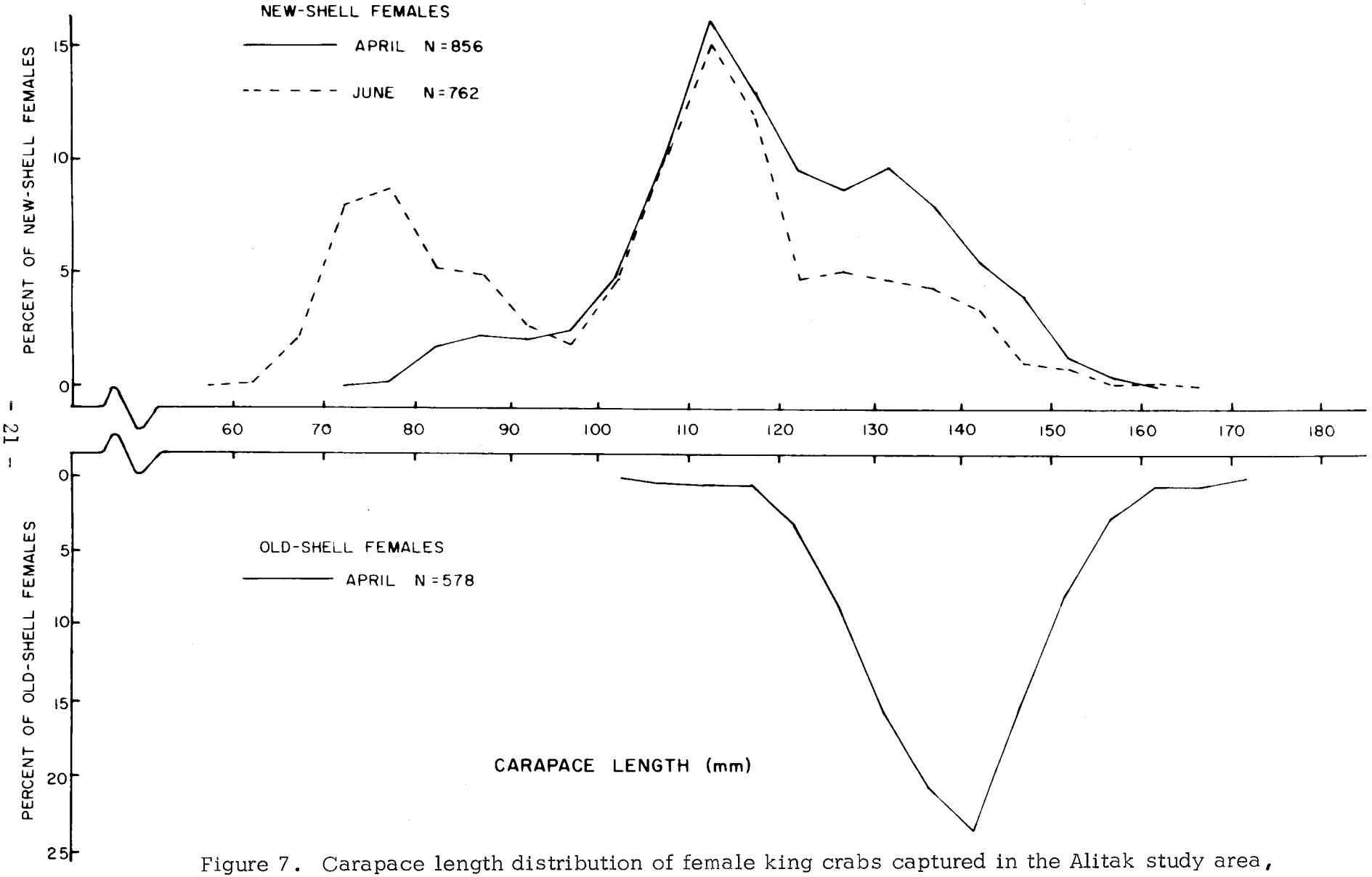

Figure 7. Carapace length distribution of female king crabs captured in the Alitak study area, April and June 1970.

does not warrant further discussion. The length distribution of the June new-shell females again exhibits a prominent mode at 112 mm and also a strong second mode at 77 mm. The absence of a group of new-shell female crabs in June corresponding to the large April old-shells is apparent. Also, during both sampling periods, female king crabs in the 90 to 99 mm length range were relatively scarce.

Sex ratios:

Sex ratio estimates for mature and immature king crabs in the Alitak study area were calculated for April and June sampling periods using estimated numbers of male and female crabs and also using unweighted totals of males and females in the trawl samples. Both methods yielded essentially the same results. The ratios (expressed as females per male) for mature crabs in April and June were 3.42:1 and 2.06:1 respectively (Table 7), while the ratios for immature crabs in April and June were 1.28:1 and 0.85:1 respectively.

Size at maturity:

The presence or absence of eggs on the pleopods of the new-shell female king crab provides a useful indicator of sexual maturity. Using this criterion, it was found that the 50 percent maturity level for female crabs was attained at about 100 mm carapace length (Figure 8). Nearly all females less than 100 mm were non-ovigerous and nearly all larger females had some external eggs. The smallest ovigerous female crabs observed were 91 mm in carapace length, although the viability of the eggs of these females was not verified. It would appear that the choice of 100 mm carapace length for the size at maturity of female king crabs was valid. Unfortunately there is no similar readily apparent indicator of sexual maturity for the male king crab.

Ovigerousness of mature females:

In April approximately 40 percent of female king crabs captured had not yet molted and macroscopic categorization of egg clutch size of very recently molted females was difficult. In addition, egg sampling and microscopic examination was performed only on a limited, trial basis. By June, nearly all females had molted and exoskeletons were firm. Improved egg sampling and examination procedures were applied on a larger scale. Thus, the June data was used exclusively for the following analysis of king crab ovigerousness.

The abundance estimates for female king crabs included estimates of the abundance of new-shell females by egg clutch size. These estimates were

Table 7. Sex ratios of king crabs in the Alitak area, April and June 1970.

Stratum	Mature crabs						Immature crabs					
	April			June			April			June		
	Female	Male	Ratio 1/	Female	Male	Ratio 1/	Female	Male	Ratio 1/	Female	Male	Ratio 1/
1	21	31	0.68	5	3	1.67	1	0	--	0	0	--
2	342	86	3.98	13	19	0.68	3	2	1.33	0	0	--
3	1,077	304	3.54	346	179	1.93	73	58	1.26	66	103	0.64
4	--	--	--	114	40	2.85	--	--	--	173	188	0.92
5	--	--	--	36	12	3.00	--	--	--	19	13	1.46
6	--	--	--	6	0	--	--	--	--	1	0	--
	1,440	421	3.42	520	253	2.06	77	60	1.28	259	304	0.85

1/ Females per male.

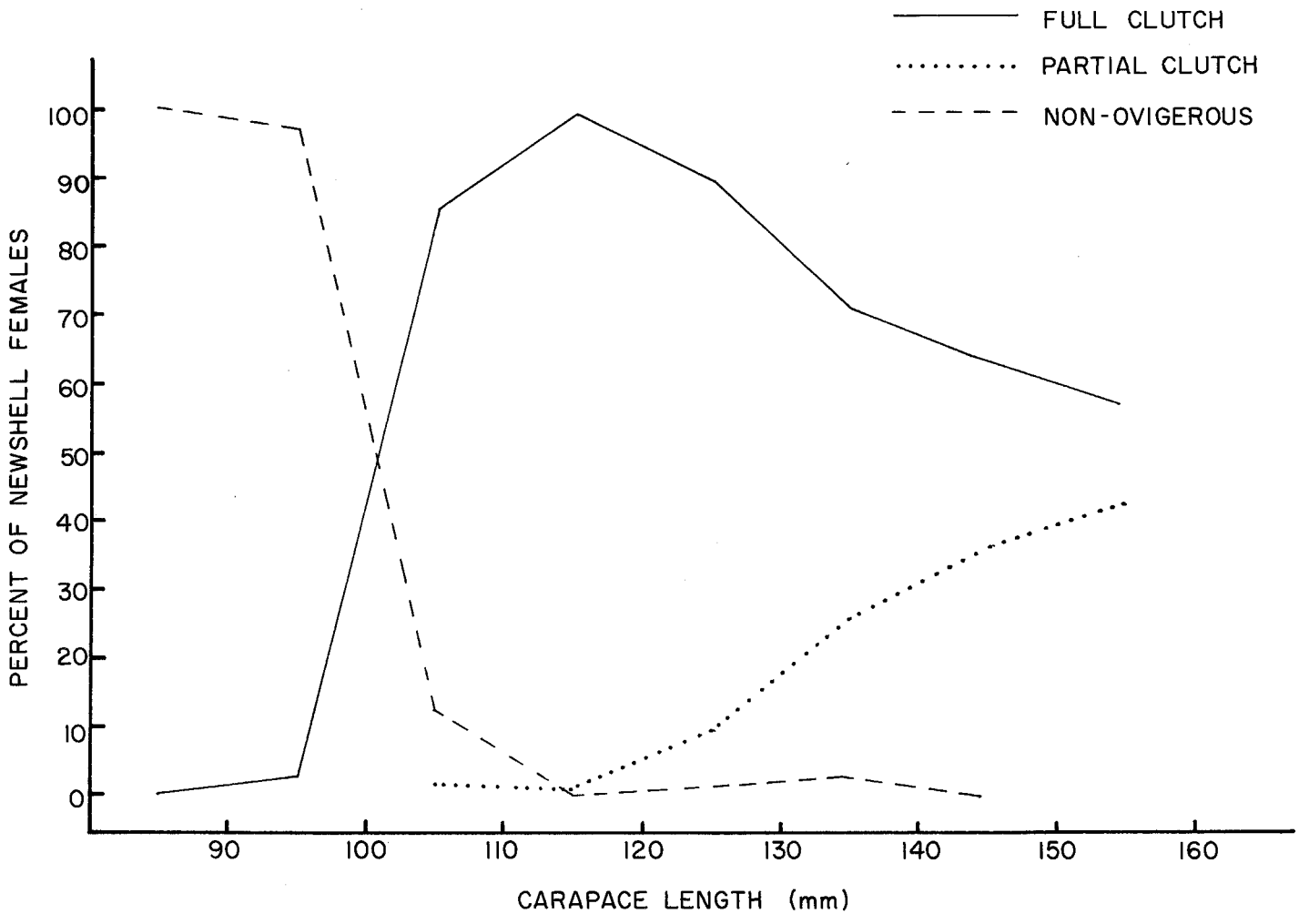

Figure 8. Relative frequency of fully ovigerous, partially ovigerous and non-ovigerous new-shell female king crabs by 10 mm size groups, Alitak study area, June 1970.

used to derive a profile of the relative abundance of fully ovigerous, partially ovigerous and non-ovigerous new-shell females. This procedure has the effect of weighting the final composition statistics for the relative area within each depth stratum and for the relative density of crabs among strata. In this manner it is estimated that 87.79 percent of mature new-shell females bore a full egg clutch, 8.87 percent bore a partial egg clutch and 3.34 percent bore no eggs (Table 8). Each of these statistics is within a few hundredths of a percent of the corresponding value generated by the unweighted data.

Earlier studies have demonstrated that female king crabs may carry unfertilized eggs on their pleopods for several months before the eggs decompose and slough off (McMullen and Yoshihara, 1969). In our research, egg samples from some of the female king crabs were examined microscopically to determine the percentage of fertilized eggs on the pleopods. Among the samples from the Alitak area, the percentage of fertilized eggs ranged from 3 to 100 (Table 9). None of the samples consisted entirely of unfertilized eggs and few samples contained more than 5 percent unfertilized eggs. The results indicate that the macroscopic examination of ovigerousness of female king crabs in the Alitak area was essentially correct, although some of the females bearing apparently full egg clutches actually carried some unfertilized eggs which would eventually be lost.

The scarcity of large females in the June samples compared to the abundance of large old-shell females captured in April has been previously noted. The discrepancy indicates a possible bias in the data on ovigerousness. Among the few large females captured in June, partial egg clutches were frequent (Figure 8). However, the frequency of females without any eggs did not increase noticeably with size, so it is probable that the relative abundance of unmated females was not underestimated.

Recapture of tagged crabs:

A total of 510 king crabs were tagged and released in the Alitak study area during 1970; 493 were males and 17 were females. Of these, 82 crabs (16%) were recovered during the 1970-71 king crab fishing season. All but one were males. Additional recoveries are anticipated during the next several years and for this reason a thorough presentation of this phase of the research will not be attempted.

However, the first year recoveries do provide some information as to the extent and direction of crab dispersion from the study area. Two general areas accounted for over 85 percent of the recoveries. Fifty-five males and the single female were recaptured in the vicinity of Alitak Bay, including specifically that portion of Stock III east of 154°34' W and north of 56°40'N. Fifteen

Table 8. Estimates of relative abundance of fully ovigerous, partially ovigerous and non-ovigerous new-shell female king crabs in the Alitak study area, June 1970.

Stratum	Full clutch		Partial clutch		Non-ovigerous		Estimated total number
	Estimated number	Percentage	Estimated number	Percentage	Estimated number	Percentage	
1	387.6	50.00	193.8	25.00	387.6	25.00	969.0
2	6,521.6	90.00	724.6	10.00	0.0	0.00	7,246.2
3	212,333.2	88.50	21,233.3	8.85	6,370.0	2.65	239,936.5
4	65,568.0	84.11	8,013.9	10.28	4,371.2	5.61	77,953.1
5	16,426.5	94.29	349.5	2.86	349.5	2.86	17,125.5
6	792.0	100.00	0.0	0.00	0.0	0.00	792.0
Total	302,028.8		30,515.1		11,478.3		344,022.2
Average		87.79		8.87		3.34	

Table 9. Percentage of fertilized eggs in samples of eggs from 191 female king crabs from the Alitak study area, June 1970.

Percent fertilized eggs	Number of samples from full clutches	Number of samples from partial clutches
96-100	146	27
91- 95	4	1
86- 90	2	-
81- 85	2	-
76- 80	-	2
71- 75	2	-
6- 70	1	1
1- 5	2	1
0	-	-
Total	159	32

males were recaptured south of Cape Ikolik, north of 56°40' N and west of 154°34' W in an area which is locally known as the Ikolik grounds. Within these two vast regions, more limited areas can be identified where most recaptures occurred. Within the Alitak area, 34 males and 1 female were taken in deep waters (45-80 fms) inside Alitak Bay and a portion of Deadman Bay (Figure 9). Of the Ikolik recaptures, 11 were taken 20-30 miles south of Cape Ikolik at depths of 50-100 fathoms.

One male was recaptured east of Chirikof Island at the boundary of Stocks II and III. Four males were taken east of Geese Islands in Stock II.

None of the crabs recaptured had grown during the time at liberty as determined by measurements coupled with examination of shell-age.

Kaguyak study area

The Kaguyak study area was found to be too rocky for adequate sampling with the beam trawl and only 12 tows were made. The replaceable center section of the trawl beam was bent on three occasions.

Only 36 king crabs were captured by trawling of which 32 were mature new-shell females. An additional 172 mature new-shell females from crab pots were examined for the presence of external eggs. Of the total of 204 females captured by trawling and pot fishing, 74 percent had a full egg clutch, 20 percent had partial clutch and 6 percent were non-ovigerous.

Egg samples from 32 apparently ovigerous females were examined to estimate the frequency of unfertilized eggs in the samples. Six of the samples were found to consist entirely of unfertilized eggs and two contained more than 5 percent unfertilized eggs (Table 10). It was concluded that the macroscopic examination over-estimated the proportion of female king crabs which had successfully mated in the Kaguyak area in 1970; it is probable that less than 90 percent of mature females had mated.

DISCUSSION

Brood stock condition

The first of the three long-term project goals stated in the introduction is to determine if selective commercial harvest of male king crabs has resulted in unbalanced brood stocks composed largely of females. The results of the present study indicate that among crabs mating in the Alitak area, sex ratios

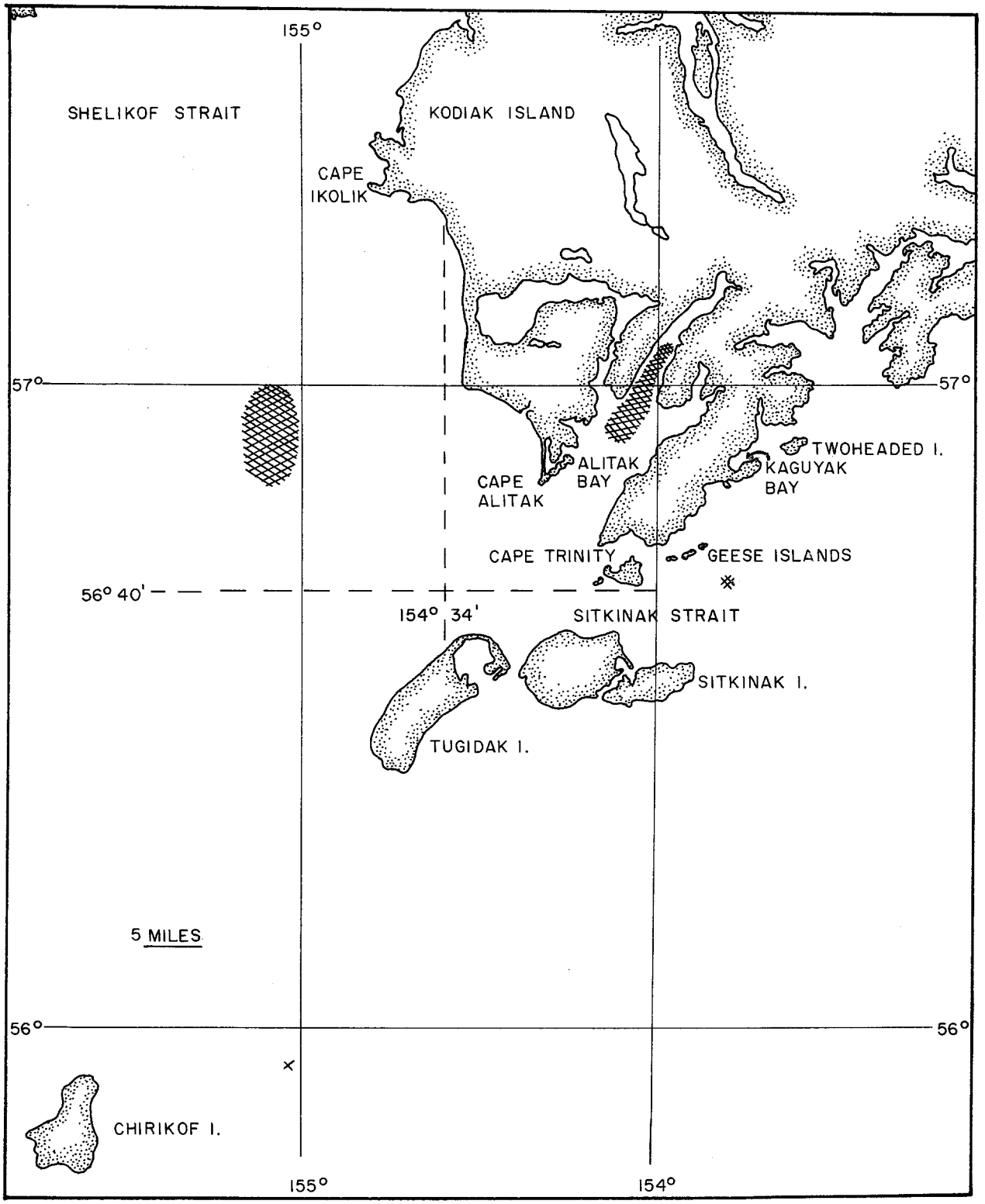

Figure 9. Location of recapture of tagged king crabs released in the Alitak study area, 1970.

Table 10. Percentage of fertilized eggs in samples of eggs from 32 female king crabs from the Kaguyak study area, June 1970.

Percent fertilized eggs	Number of samples from full clutches	Number of samples from partial clutches
96-100	15	9
91- 95	-	2
1- 90	-	-
0	2	4
Total	17	15

were essentially balanced during the 1970 mating season and that nearly all mature females had mated. At the height of the mating season in late April, mature females outnumbered mature males, but only by a margin of 3.4 to 1. This is slightly more balanced than the ratio of 5.6:1 observed in the same area in May 1969[3/] and approaches the 2:1 ratio observed there in May 1962 (Gray and Powell, 1966). The sex ratios expressed here do not account for other factors which may influence mating success in king crab populations, including shell-age composition of males and size distributions of male and female crabs. However, the estimate that 96 percent of mature females had mated by the end of June indicates that these additional factors probably had no significant adverse effect in the Alitak area in 1970.

The limited sampling in the Kaguyak area suggests that sex ratios there were not as favorable; however, this area was not sampled until the end of the mating season in June and too few crabs were captured by trawling to yield a reliable estimate of sex ratios.

Size composition

The second project goal is to determine how age-class abundance of king crabs is related to brood stock condition. Until the progeny of studied brood stocks reaches a large enough size to enter sample catches, the question cannot be answered. The initial approach has been to develop techniques of sampling a broad range of sizes of crabs and to document the major features of size distributions.

The prominent peaks and troughs observed in the carapace length-frequency distributions of female and new-shell male king crabs probably represent fluctuations in abundance of age classes. Similar features in the length distributions of immature king crabs have been observed by several others (Powell, 1967; Weber, 1967). Comparison of size distribution patterns from the same area over a period of several years will be necessary to make sure that the features are not anomalies resulting from crab distribution or the sampling techniques used. At present it would appear that analysis of size distributions of sublegal males may provide a valuable means of estimating recruitment.

Abundance

The remaining long term project goal is to determine if desired levels of

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3/ ADF&G unpublished data.

harvest can be established for king crab stocks based upon knowledge of crab abundance, biology and catchability. The initial step toward this goal has been to develop techniques to estimate crab abundance, beginning in the Alitak study area, where sublegal male crabs are abundant. Although the variance of the estimates was high, it may be minimal as compared to the year-to-year population fluctuations. At present, precise estimates of this fluctuation are not available. However, it is anticipated that repeated sampling over several years will yield these estimates.

The practical value of our abundance estimates depends upon the degree of certainty which the biologist wishes to place on them. If he is satisfied with 70 percent certainty, the confidence interval will, of course, be much smaller than for 90 or 95 percent certainty. If year-to-year fluctuation proves to be substantial, it would seem that 70 percent confidence in estimating abundance would be adequate.

SUMMARY

1. During sampling cruises in April and June, 110 tows were made with a beam trawl in a study area in the vicinity of Alitak Bay at the south end of Kodiak Island. A stratified two-stage sampling design was followed.

2. A total of 3,334 king crabs were captured in the trawl hauls. Data were collected on size and sex composition of the samples and ovigerousness of females.

3. The sampling indicates that the sex ratio of mature king crabs was not adversely unbalanced and that nearly all mature females had mated during the 1970 mating season. A group of large females, prominent as old-shell crabs in the April catches, was not found in the June distribution.

4. Size distributions of male and female king crabs indicated prominent modes and troughs which probably represent successful and unsuccessful year classes. Analysis of data of this type from future years combined with analysis of the composition of the commercial catch may result in technique of prediction of recruitment.

5. Data from sample tows in the Alitak study area were used to calculate stratified estimates of crab numbers and density for April and June 1970; the estimates were 1.4 million and 923,000 crabs respectively. Estimates include only crabs 60 mm in carapace length or greater. Average density of crabs decreased from April to June from 23,058 to 7,082 crabs per square mile.

6. A total of 510 king crabs was tagged and released in Alitak study area, of which 82 were recaptured during 1970-71 king crab fishing season. Movement to deeper waters seaward and into Alitak Bay was indicated.

7. The Kaguyak area was found to be too rocky for sampling with beam trawl. Additional crabs from crab pots were examined. Mating success appeared to have been poorer there in 1970 than in Alitak area.

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Appendix Table 1. Stratification of study areas.

Alitak Study Area

Stratum	Depth (fms)	Block Numbers	Stratum Area	Percent of Total Area	Avg. Area of Blocks	Range of Block Areas
1	5- 9	1- 6	5.77	4.43	0.96	0.85 - 1.19
2	10-19	7-23	17.20	13.19	1.01	0.79 - 1.21
3	20-29	24-43	37.88	29.07	1.90	0.91 - 2.30
4	30-39	44-75	64.92	49.82	2.03	1.11 - 2.70
5	40-49	76-81	4.16	3.19	0.69	0.31 - 1.36
6	50-59	82	0.39	0.30	0.39	-
Total Area			130.32			

Kaguyak Study Area

Stratum	Depth (fms)	Block Numbers	Stratum Area	Percent of Total Area	Avg. Area of Blocks	Range of Block Areas
1	10-19	1- 6	8.07	14.56	1.34	0.22 - 2.02
2	20-29	7-26	28.78	51.90	1.44	0.75 - 1.72
3	30-39	27-39	16.44	29.65	1.26	0.23 - 2.02
4	40-49	40-41	2.16	3.89	1.08	0.41 - 1.75
Total Area			55.45			

Appendix Table 2. King crab abundance and density estimates by stratum, Alitak study area, 1970.

Stratum	Females			Males			Total king crabs	
	Estimated number	Standard error	Density (crabs per sq. mi.)	Estimated number	Standard error	Density (crabs per sq. mi.)	Estimated number	Density (crabs per sq. mi.)
APRIL								
1	10,659.0	4,568.6	1,847.3	15,019.5	5,721.8	2,603.0	25,678.5	4,450.4
2	246,372.5	141,864.6	14,324.0	60,868.5	31,170.1	3,538.9	307,241.0	17,862.8
3	813,944.2	313,546.9	21,487.4	256,215.4	91,011.4	6,763.9	1,070,159.6	28,251.3
1-3	1,070,975.0	344,177.2	17,600.2	332,103.2	96,371.0	5,457.7	1,403,078.2	23,058.0
JUNE								
1	1,356.6	682.4	235.1	581.4	477.3	100.8	1,938.0	335.9
2	7,246.3	4,164.7	421.3	7,970.9	3,688.3	463.4	15,217.2	884.7
3	291,604.2	95,586.1	7,698.1	199,593.3	67,808.7	5,269.1	491,197.5	12,967.2
4	209,089.0	117,512.7	3,220.7	166,105.6	112,190.0	2,558.6	375,194.6	5,779.3
5	25,863.0	19,339.5	6,217.1	12,582.0	7,337.9	3,024.5	38,445.0	9,241.6
6	924.0	648.4	2,369.2	0.0	-	0.0	924.0	2,369.2
1-6	536,082.9	152,768.3	4,113.6	386,833.1	131,347.9	2,968.3	922,916.0	7,081.9

Appendix Table 3. Carapace length distribution of new-shell male king crabs captured in the Alitak study area, April 1970 1/.

Carapace length (mm)	Number of crabs by stratum 1	2	3	Total	Percent of grand total
70- 74			1	1	0.24
75- 79					
80- 84			12	12	2.93
85- 89		1	18	19	4.63
90- 94		1	12	13	3.17
95- 99			15	15	3.66
100-104	1	4	18	23	5.61
105-109		4	21	25	6.10
110-114	3	7	24	34	8.29
115-119	3	10	40	53	12.93
120-124	6	10	36	52	12.68
125-129	4	17	41	62	15.12
130-134	4	7	28	39	9.51
135-139	2	4	16	22	5.37
140-144	3	2	17	22	5.37
145-149		1	6	7	1.71
150-154			6	6	1.46
155-159	1	1	1	3	0.73
160-164	1			1	0.24
165-169			1	1	0.24
Total	28	69	313	410	

1/ Excludes one new-shell male king crab not measured due to carapace damage.

Appendix Table 4. Carapace length distribution of old-shell male king crabs captured in the Alitak study area, April 1970.

Carapace length (mm)	Number of crabs by stratum 1	2	3	Total	Percent of grand total
110-114			1	1	1.43
115-119			1	1	1.43
120-124			2	2	2.86
125-129		1	3	4	5.71
130-134			2	2	2.86
135-139	1	1	4	6	8.57
140-144		4	7	11	15.71
145-149	1	4	5	10	14.29
150-154			6	6	8.57
155-159		4	9	13	18.57
160-164	1		5	6	8.57
165-169		3		3	4.29
170-174		1	1	2	2.86
175-179		1	1	2	2.86
180-184			1	1	1.43
Total	3	19	48	70	

Appendix Table 5. Carapace length distribution of new-shell male king crabs captured in the Alitak study area, June 1970.

Carapace length (mm)	Number of crabs by stratum						Total	Percent of grand total
	1	2	3	4	5	6		
50- 54				1			1	0.18
55- 59								
60- 64			2	4			6	1.10
65- 69			2	24			26	4.75
70- 74			8	47	1		56	10.24
75- 79			13	53			66	12.07
80- 84			18	28	5		51	9.32
85- 89			26	11	2		39	7.13
90- 94			22	12	5		39	7.13
95- 99			11	8			19	3.47
100-104			13	4			17	3.11
105-109		2	23	3			28	5.12
110-114			26	4	2		32	5.85
115-119		4	27	3	5		39	7.13
120-124		5	27	9	1		42	7.68
125-129	1		25	6			32	5.85
130-134	1	4	19	2	1		27	4.94
135-139			6	2	1		9	1.65
140-144	1		5				6	1.10
145-149			2	2			4	0.73
150-154			2				2	0.37
155-159				2	1		3	0.55
160-164			1				1	0.18
165-169		1	1				2	0.37
Total	3	16	279	225	24	0	547	100.02

Appendix Table 6. Carapace length distribution of new-shell female king crabs captured in the Alitak study area, April 1970.[1/]

Carapace length (mm)	Number of crabs by stratum 1	2	3	Total	Percent of grand total
75- 79			2	2	0.23
80- 84		1	14	15	1.75
85- 89			19	19	2.22
90- 94			18	18	2.10
95- 99	1	1	20	22	2.57
100-104		6	36	42	4.91
105-109	1	18	67	86	10.05
110-114	1	36	101	138	16.12
115-119	1	41	69	111	12.97
120-124		32	50	82	9.58
125-129	5	35	35	75	8.76
130-134	1	39	43	83	9.70
135-139	1	22	45	68	7.94
140-144		20	27	47	5.49
145-149		16	18	34	3.97
150-154		4	7	11	1.29
155-159		1	2	2	0.35
Total	11	272	573	856	

1/ Excludes 35 new-shell female king crabs not measured due to carapace damage.

Appendix Table 7. Carapace length distribution of old-shell female king crabs captured in the Alitak study area, April 1970[1/].

Carapace length (mm)	Number of crabs by stratum 1	2	3	Total	Percent of grand total
105-109			2	2	0.35
110-114			3	3	0.52
115-119		1	2	3	0.52
120-124		2	17	19	3.29
125-129		3	47	50	8.65
130-134	2	7	81	90	15.57
135-139	1	11	107	119	20.59
140-144	7	15	113	135	23.36
145-149	1	14	74	89	15.40
150-154		6	40	46	7.96
155-159		5	11	16	2.77
160-164		1	2	3	0.52
165-169			3	3	0.52
Total	11	65	502	578	

1/ Excludes 48 king crabs not measured due to carapace damage.

Appendix Table 8. Carapace length distribution of new-shell female king crabs captured in the Alitak study area, June 1970 1/.

Carapace length (mm)	Number of crabs by stratum						Total	Percent of grand total
	1	2	3	4	5	6		
60- 64				1			1	0.13
65- 69				15	1		16	2.10
70- 74			3	57	1		61	7.99
75- 79			9	56	2		67	8.79
80- 84			17	18	5		40	5.25
85- 90			17	16	5		38	4.99
90- 94			9	8	4		21	2.76
95- 99			10	2	1	1	14	1.84
100-104			27	6	2	1	36	4.72
105-109		2	48	20	7		77	10.10
110-114		3	82	21	7	2	115	15.09
115-119	1	1	66	16	5	1	90	11.81
120-124			28	6	2		36	4.72
125-129		1	29	5	2	2	39	5.12
130-134	1	3	23	8	1		36	4.72
135-139	2	1	16	9	5		33	4.33
140-144		2	13	8	3		26	3.41
145-149			5	2	1		8	1.05
150-154			1	5			6	0.79
155-159			1				1	0.13
160-164				1			1	0.13
Total	4	13	404	280	54	7	762	99.97

1/ Excludes one female crab not measured due to carapace damage.